The Analysis of a Three-Point Mounted Ripper Compared to a Drawbar Pull Behind Ripper

by

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ABSTRACT

This senior project is an analysis and comparison of a three-point mounted ripper compared to a drawbar pull behind ripper. This will provide Baptista Farms with better insight into which method would better suit their needs. Since there are different situations created by different soil types, ripper shank configuration, soil moisture content, and tractor setup, an in depth analysis is needed. The result of this project will be a hitch method that will provide less tractor wear, while still providing the desired ripper depth and acceptable wheel slip. Also, the project includes a results and discussion section that presents recommendations for a better, more accurate test and a conclusion to which method is recommended for Baptista Farms.

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INTRODUCTION

Background

Baptista Farms is a family owned farm located in Stevinson, CA, consisting of a combination of almonds, alfalfa, corn, black-eye beans, and oats. Increasing the size of planting, tillage, and harvesting equipment used, has resulted in increased ground compaction. The farm consists of a soil type that is mainly Hanford Sandy Loam. Due to the previously mentioned conditions, sub soil tillage is now required before every crop is planted in the fall and spring.

Sub soil tillage is a process by which metal shanks are pulled through the ground to tear up the soil. It aerates the soil leaving it looser allowing the plant's roots to easily grow deeper into the ground. It also allows the water to soak deeper into the soil instead of just running over the top during irrigations. If the water isn't absorbed into the soil, the crop will not have a sufficient supply of water to last until the next irrigation.

Justification

Baptista Farms currently uses a 350 horsepower tractor that pulls a ripper (sub soil tillage implement) that mounts on the three-point hitch of the tractor. This configuration is effective because the suction (downward) force created by the ripper pulls down on the tractor supplying the weight and traction needed to pull the ripper. Due to inconsistencies in the field, where some spots are harder than others, ripper draft increases. This force is constantly changing and could cause varying degrees of downward force on the rear axle of the tractor. These inconsistencies result in excessive weight being put on the back axle causing premature wear on equipment. Therefore, Baptista Farms wants to explore alternative methods of pulling a ripper to reduce equipment wear while still providing effective sub soil tillage for the various crops.

The objective of this senior project is to analyze and compare a three-point mounted ripper to a drawbar pull behind ripper.

LITERATURE REVIEW

Sub Soiling

Why do you sub soil? There are many different reasons why people sub soil such as breaking up the layers below normal tillage depths, increasing the water infiltration, water drainage, and increasing root penetration. But the most important advantage is it breaks up the compacted layers, loosening the soil without greatly disturbing the topsoil. Some farms are moving away from this and switching to a no-till method for cost reasons.

If the farm is in a location where the winter is cold and the ground freezes it is not necessary to sub soil. The reason for this is due to the expansion of water freezing with great force causing it to swell. This happens because water expands when it changes from liquid to ice, it leaves the ground less compact when it changes back to the liquid state. However, California typically does not get cold enough during the winter to freeze the soil, so farmers have to sub soil in order to keep their crops growing and keep the soil loose.

Hitching Methods

There are two different ways to pull a sub soil tillage implement, also known as a ripper. This piece of equipment is pulled with a tractor and can be mounted on the tractor's three-point hitch, or on the tractor's draw bar hitch. Both methods have their advantages and disadvantages. A three-point mounted ripper supplies it's own weight to the tractor giving it the necessary traction to pull the ripper. This allows the tractor to be light when it is not ripping yielding the least amount of ground compaction. The disadvantage of a three-point ripper is it puts excessive weight on the rear axle of the tractor. The advantage of a pull behind ripper is that it doesn't put an excessive weight on the rear axle and you can properly ballast the tractor. The disadvantages of a pull behind ripper include the tractor always being heavy from the additional ballasts, and it can be less efficient due to the increased wheel slip.

Drawbar Hitch. When tractors where first created they had the implement mounted directly on the tractor. This changed as tractors were used for more than one function; the tractors and implements quickly became individual units. A drawbar hitch became the way an operator attached an implement to a tractor. This allowed the two to be joined by one point directly in line with the tractor. Some drawbars even had a swinging feature that allowed the hitch to move from side-to-side so that the line of draft was correct with the tractor. In the early days, plows were implements that pulled the hardest and had gauge wheels to control the depth and allowed transportation down the road (Morling). This depth control worked as long as the soil was consistent and was not too hard. If the soil was hard, the plow could come out of the ground and would not work the ground to the desired depth. When pulling an implement with a drawbar hitch it will eventually get to a point where added weight on the tractor is needed to decrease the wheel-slip in order to preform the tillage operation (Khatti). Even now, the drawbar hitch is still a very common method to hitch implements to tractors, especially on a four-wheel drive articulating tractor where a 55/45 weight distribution is desired. The drawbar hitch is also used when an implement is too heavy to be mounted on the three-point hitch. Today tractors range in size from 5 horsepower to over 600 horsepower; this range requires different sized drawbars to safely allow the tractor to pull an implement. The different categories of drawbar hitches can be found in Table 1.

Table 1. Drawbar Hitch Categories.

Category	Max Tractor PTO Horsepower
0	38
I	64
II	154
III	248
IV	402
V	671

Three-point Hitch. Before the three-point hitch, each tractor manufacturer had a different way to mount an implement on their tractor. This ensured that the customers purchased the same brand of tractor and implements. In 1935, Harry Ferguson developed the three-point hitch after experimenting for 17 years, and in 1936, Ferguson started selling small tractors with a three-point hitch. There are two different types of three-point hitches: a free-floating hitch, and a force control system (Morling). The Ferguson hitch used a force control system, also known as a draft control system, which worked well (C. E. Goering). A force control system automatically adjusts for the varying amount of draft, raising the implement when the draft increases and lowering it when draft decreases. This allows for a constant draft load to be placed on the tractor even when the load is varying due to the inconstancies in a field. The sensitivity of the draft control system can be adjusted, lifting the implement with even the slightest amount of draft. A free-floating hitch is simply a three-point hitch without a draft control, which does not change the implement depth with the changing draft loads. Ferguson was able to offer customers a lighter tractor with the three-point hitch due to the dynamic load transfer from the implement and front wheels of the tractor to the rear drive wheels (Morling). In 1959, the American Society of Agricultural Engineers (ASAE) standardized the three-point hitch so all implements and tractors could easily be interchangeable (C. E. Goering). There are different sized three-point hitches for various sizes of tractors and implements. As tractors and implements increase in size the hitch also needs to be bigger to handle the greater loads and stresses. As you can see from the Table 2 below, there are five different categories of three-point hitches with a standardized size.

Table 2. Three-Point Hitch Categories.

Category	Hitch pin size		Lower hitch spacing	Tractor drawbar power
	upper link	lower links		
0	17 mm (5⁄8")	17 mm (5⁄8")	500 mm (20")	<15 kW (<20 hp)
1	19 mm (3⁄4")	22.4 mm (7⁄8")	718 mm (26")	15-35 kW (20-45 hp)
2	25.5 mm (1")	28.7 mm (1 1⁄8")	870 mm (32")	30-75 kW (40-100 hp)
3	31.75 mm (1 1⁄4")	37.4 mm (1 7⁄16")	1010 mm (38")	60-168 kW (80-225 hp)
4	45mm (1 3⁄4")	51 mm (2")	1220 mm (46")	135-300 kW(180-400hp)

Tractor Configurations

There are many different ways tractors can be configured, which varies from tire size and location of the drive wheels. Two-wheel drive tractors have the drive wheels in the rear and the front wheels are for steering. There are different types of two-wheel drive tractors such as a standard tread tractor where the widths of the wheels are fixed. A row crop tractor, which the front and rear wheels are adjustable so they can be adjusted to match the spacing of the row crop. Another is a high profile and low profile tractor, which can either have high ground clearance or be low to the ground to fit in confined areas such as orchards or buildings. Four-wheel drive tractors are also another configuration; with this system the tractor has all four wheels providing power to the ground. A front-wheel auxiliary drive, or front-wheel assist tractor, is similar to a two-wheel drive tractor where the main drive tires are in the rear of the tractor but when it is necessary you can send power to the front wheels as well. The front wheels on these tractors are normally bigger than a two-wheel drive tractor’s front wheels, but they continue to be used for steering the tractor even though they put power to the ground. A true four-wheel drive tractor has all wheels the same size on the front and rear. Normally, these tractors have an articulated arrangement where the axles are non-steering and attached to a sub frame connected at a center point (Borgman). This configuration is more common in the high horsepower tractors used today with eight tires, two on each side, front and back. However, a three-point hitch is not commonly found on these tractors. The dynamic weight transfer force created by a 600 horsepower tractor would add a lot of weight to the rear axle which can be hard on the tractor since it is supposed to share the load equally. This is why it has the same size tires and axles on the front and rear. So normally the tractor’s drawbar hitch is used to pull implements, and ballasts are added to the tractor so the weight is distributed correctly.

PROCEDURES AND METHODS

The scope of this project is intended to compare a three-point mounted ripper to a drawbar pull behind ripper to determine which method will create less wear on the tractor while still providing effective sub soil tillage for the crops. It is intended that this project will offer insight as to which hitch method will be better for Baptista Farms to complete their subsoil tillage operation. For this project an Allis Chalmers 305 4wd articulating tractor will be used with a 5-shank three-point ripper that was built in house. To reduce the amount of variables affecting the hitching method a tool carrier will be used to pull the ripper with the drawbar hitch so the same ripper can be used by both hitching methods.

Project constraints

For the ripping to be completed in a timely manor it is important that the tractor is able to move at least 2.5 MPH. Also, it is important that there is not an excessive amount of wheel slip because too much wheel slip will cause the tractor to burn more fuel and causes more wear on the tires, so it is imperative that the wheel slip stays below 145%.

3-point down force calculations

In order to determine which method will put more weight on the rear axle of the tractor, moment calculations have to be done so that each method can be compared to determine which puts less weight on the rear axle. First the shanks on the ripper where measured so that the downward force they produce when being pulled through the ground can be determined. When the ripper is 18in. deep it has a horizontal distance of 20-¾ in. to the shank. So with a force of 160lb per shank, per inch of depth, that shank has a draft of 2,880lb. Using cross multiplication it can be determined that when there is 2,880lb of draft per shank it creates a down force of 2,498lb per shank. With the configuration of the ripper with 5 shanks 30 inches apart there are two shanks that are 75in. from the rear axle and there are three shanks are 101-5/8in. from the rear axle. Taking these distances into consideration the total downward force added to the rear axle from the ripper when it is 18in. deep is 9,019lb. A chart containing the downward force for various depths can be found in appendix B along with the formulas used in appendix C.

Adding ballast to the tractor

After determining that Baptista Farms had 14 cast iron wheel ballasts available for use on the tractor, the front and rear axles where weighed to determine how much weight should be added to each axle to have the appropriate weight distribution for an articulating four-wheel drive tractor. Without any additional weight on the tractor the front axle weighs 18,370lb and the rear axle weighs 11,870lb. That puts 61% of the weight on the front axle and 39% on the rear. This weight distribution is within the 55-65% on the front axle and

45-35% on the rear axle for implements causing high down loads using the three-point hitch (Borgman). This weight distribution also explains why the tractors have worked so well with the three-point hitch over the years. However for a standard tow implement the four-wheel drive tractor should have 51-55% on the front axle and 49-45% on the rear axle (Borgman). To achieve this balance ten wheel weights where added to the rear axle with, three on each inside rim and two on each of the outside rims. This brought the rear axle weight up to 15,870lb. Four weights where added to the front, two on each inside rim making the front axle 19,970lb. This makes the weight distribution 55% in the front and 45% in the back, which is within the recommended distribution. Since the drawbar is 18 ¾in. high, the weight transfer from the front to rear axle when the ripper is 18in. deep is about 2,100lb. So when the tractor is pulling a load the front axle will weigh 17,870lb and the rear will be 17,970lb. This puts the tractor at the perfect weight distribution since a true four-wheel drive tractor has the same size wheels in the front and rear the load should also be distributed equally.

Initial Testing

Once all the iron weights were put on the tractor, there was a one acre field that the tractor was tested on to see if it had enough weight to pull the ripper with the drawbar as you can see in Figure 1. Also, since the tool carrier hasn't been used in many years it needed to be tested as well to ensure it would work during testing.

Figure 1. Tractor Hooked Up For Initial Testing.

The tractor preformed better than expected with the initial test and it was determined that if the tractor needed additional ballast to pull the ripper water could easily be added to the tires. Added ballasts increases the soil compaction, which could retard the growth of crops (Borgman). Therefor it is key to have the tractor perform as desired with the least amount of weight possible, and less weight on the tractor will also cause less wear.

Testing With The Drawbar pull

After the winter crop was chopped off for silage, fertilizer was spread onto the field, which was then disked. After disking the ground it was time to begin ripping. Figure 2 shows the Trimble EZ guide 150 that was set up in the tractor to determine the speed in order to calculate the percent wheel slip. It also allowed for the tractor to skip passes so that when the ripper was mounted to the three-point hitch it could be pulled right along side the pass made by the drawbar pulled ripper.

Figure 2. Trimble GPS in Tractor.

It was determined that the speed of the tractor when it was unloaded was 3.2MPH, Table 3 shows the percent wheel slip when the tractor was loaded.

Table 3. Tractor Wheel Slip.

Speed Loaded, MPH	% Wheel Slip
3.2	0%
3.1	3%
3	6%
2.9	9%
2.8	13%
2.7	16%

The best speed to operate the tractor at would be 3.0-2.9 MPH to have the correct wheel slip when pulling the ripper. If the wheel slip becomes to great it will cause the tractor to stop moving and just spin, or it can also cause the tractor to hop up and down which is also known as power hop or wheel hop. A steel rod was used to check the depth of the ripper, which ranged from 18in.-20in. This was the depth desired by Baptista Farms thus no extra ballasts were needed. After determining if the tractor had the proper amount of weight on it and if it was able to pull the ripper deep enough, the tractor was taken to the field to be used for the testing. Once ripping in the field, it was determined that 3.0-2.9 MPH was the best speed to pull the ripper because any slower was too much of a load and could easily cause the tractor to stop or start hopping. The speed was kept constant by lifting and lowering the ripper. The GPS was used such that two passes were skipped and every third row was taken, as you can see in Figure 3.

Figure 3. Skipping two passes and Drawbar Pulled ripper.

Skipping the two passes allowed for the three-point hitch passes to be near the drawbar passes. Then, as the ground changed throughout the field, both pulling methods were still comparable. Once the passes were made across the entire field, it was time to change to the three-point mounted ripper.

Three-Point Mounted

In order to have a fair comparison, all the added ballasts were taken off the tractor back to its original weight distribution of 61% of the weight on the front axle and 39% on the rear, which is correct when a large downward force is put on the rear of the tractor. In order to determine the difference between the passes that were made by the ripper with the drawbar versus the three-point, a ring roller was pulled behind the ripper when it was attached to the three-point, as you can see in Figure 4.

Figure 4. Ripper mounted on the Three-point.

The draft from the ring roller is irrelevant because it is so small compared to the draft created by the ripper. The draft control was adjusted in order to maintain a load that kept the same wheel slip of 6-9% at the speed of 3.0-2.9 MPH. By doing this, the tractor draft control would automatically raise and lower the ripper to keep the wheel slip constant. Then the rest of the field was ripped by filling in all the remaining passes left from ripping with the drawbar pull.

Collecting Data

Once the field was completely ripped, data was collected. A steel bar was used to stick down the ripper shank path and a tape measure was used to measure how deep the ripper penetrated the soil. Fifteen random spots were selected in order to get a good representation of the entire field and the harder and softer spots.

RESULTS AND DISCUSSION

After pulling the ripper with both methods, the advantages and disadvantages of both became very apparent. The data was collected from 15 random test spots throughout the field and can be found in Figure 5, whereas the spread sheet with the numbers are in Appendix D. Each depth measurement taken could have an error of $\pm$1in. because the ripper lifts the ground when it was pulled through the soil. This makes it difficult to determine where the original soil line was in order to use it as a reference point. The amount of lift the soil had from the ripper varies; therefore, it is important to use the original soil line as a reference. Another thing that could be determined from Figure 5 is that the three-point mounted ripper depth varied a lot more than the drawbar pull. This could be due to the draft control constantly raising and lowering the ripper to maintain a constant load on the tractor.

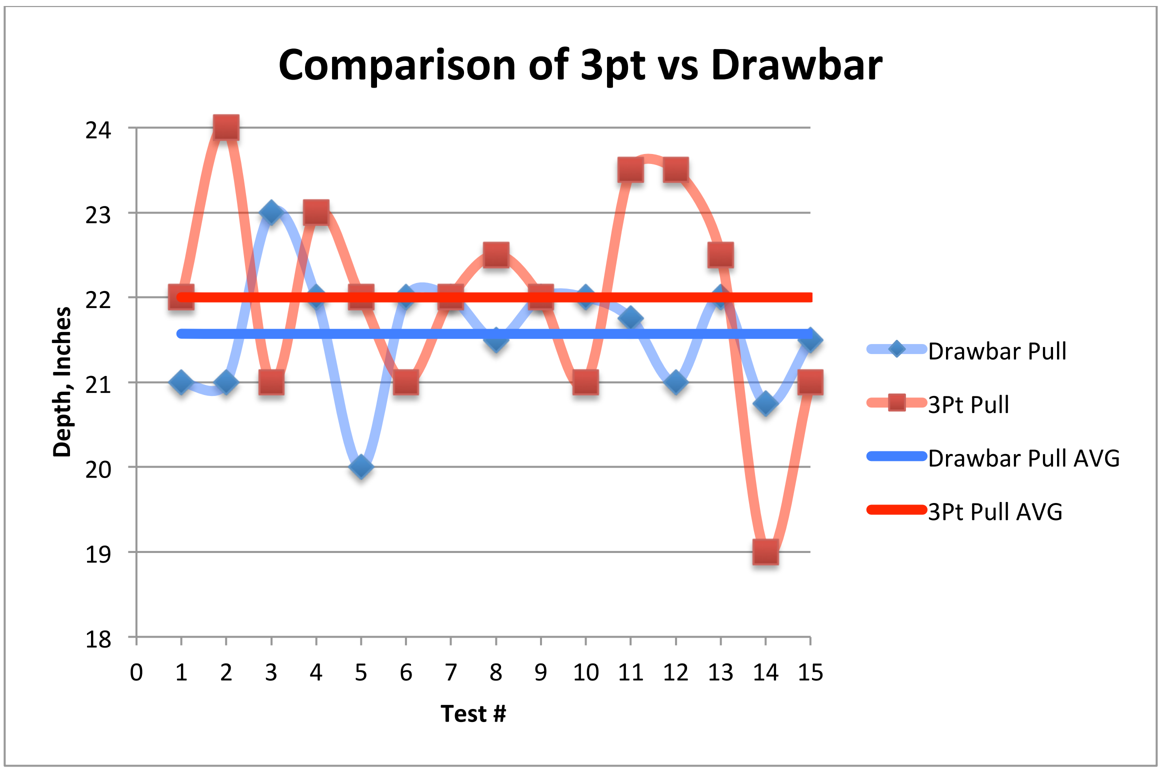

Figure 5. Depths from both methods.

Considerations

When the ripper was pulled with the draw bar, it averaged a depth of 21-½in., which is only a ½in. shallower than the three-point mounted rippers depth of 22in. There are many other different variables to consider when making a decision as to which method will work better for Baptista Farms. For example, the drawbar pull method requires the ballasts to be bolted onto the wheels so the tractor is always going to be 5,600lb heavier as compared to the three-point hitch. Once the ripper is not in the ground creating down force the tractor is lighter again. Or if a deeper depth is desired or the ground is harder which requires more draft, the three-point ripper will just add more weight to the tractor making it able to pull it, whereas with the drawbar hitch the tractor would need more weight added to the tractor in order to pull the increased draft.

Baptista Farms Recommendations

After analyzing all the different considerations it is recommended that Baptista Farms use the drawbar pull method to perform their subsoil tillage operation. This method is recommended because there was only a ½in. difference in depth seen from the two different methods and ½in. will not make a significant difference in crop production. Also, they have other tractors available that could be used to disc after the ground is ripped to reduce ground compaction. The tractor was able to rip just about as deep with only an additional 5,600lb added to the tractor which is considerably less than the 9,000lb added to the tractor from the down force of the three-point hitch. So using the drawbar to pull the ripper eliminates the varying downward force created by the suction of the three-point mounted ripper.

RECOMMENDATIONS

The testing and data collected from this project was very useful and offered excellent insight to which method would be better for Baptista farms. However, if this test was to be repeated there are a few additional things that could be done to improve it. More acres to test on, a bigger test field or multiple test fields would offer more data and a broader range of soil types affecting the draft created by the ripper. Also, another useful tool that is very important is fuel economy. Having a diesel pump that tells you how many gallons you use can offer other important data to determine which method uses more fuel or if they both have similar fuel consumption. A better GPS system would also be able to map how many acres were done in a day to determine the field efficiency and see if the three-point method is more field efficient by being faster around the turns because it can lift and lower faster as well as straighten out in a timely manner. These recommendations are a few things that could be changed to make for a better experiment for other important considerations that could be affected by the hitching method used to pull a ripper.

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APPENDICIES

Appendix A: ASM Contract & How PROJECT MEETS REQUIREMENTS OF THE ASM MAJOR

ASM Project Requirements

The ASM senior project must include a problem solving experience that incorporates the application of technology and the organizational skills of business and management, and quantitative, analytical problem solving. This project addresses these issues as follows.

Application of agricultural technology

The project will involve the application of engineering equations, tractor mechanical systems, and GPS technologies.

Application of business and/or management skills

The project will involve business/management skills in the areas of machinery management, cost and productivity analyses.

Quantitative, analytical problem solving

Problem solving will be analyzing different methods to pull a ripper, weight transfer, and wheel slip calculations.

Capstone Project Experience

The ASM senior project must incorporate knowledge and skills acquired in earlier coursework (Major, Support and/or GE courses). This project incorporates knowledge/ skills from these key courses.

- BRAE 129 Lab Skills/Safety
- BRAE 141 Agricultural Machinery Safety
- BRAE 142 Machinery Management
- BRAE 203 Agricultural Systems Analysis
- BRAE 301 Hydraulic/Mechanical Power Systems
- BRAE 321 Ag Safety
- BRAE 343 Mechanical Systems Analysis
- BRAE 418/419 Ag Systems Management
- ENGL 145 Technical Writing

ASM Approach

Agricultural Systems Management involves the development of solutions to technological, business or management problems associated with agricultural or related industries. A systems approach, interdisciplinary experience, and agricultural training in specialized areas are common features of this type of problem solving.

Systems approach

The project involves the comparison of a three point mounted ripper to a pull behind to see if a pull behind ripper can still go just as deep and the tractor can pull it just as fast without having excessive weight being put on the rear axle of the tractor.

Interdisciplinary features

The project touches on aspects of mechanical systems, agricultural safety, and GPS technology.

Specialized agricultural knowledge

The project applies specialized knowledge in the areas of tractor operation, GPS systems, and agricultural safety.

California Polytechnic State University	December 5, 2013	
BioResource and Agricultural Engineering Department	Baptista, Devin	
ASM Senior Project Contract	005805406	ASM

Project Title

To analyze a three-point mounted ripper compared to a drawbar pull behind ripper.

Background Information

Sub soil tillage is a process by which metal shanks are pulled through the ground to tear up the soil and aerates it. A three-point mounted ripper is effective because the ripper pulls down on the tractor supplying the weight and traction needed to pull the ripper. Due to inconsistencies in the field where some spots are harder than others, causing the ripper to pull harder, this force is constantly changing and could cause varying degrees of downward force on the back of the tractor. These inconsistencies result in excessive weight being put on the back axle causing premature wear on the equipment.

Statement of Work

The first phase of this senior project will be to research to calculate how the tractor should be ballasted for a pull behind ripper. The second phase will be to put ballasts on the tractor and acquire data from pulling the ripper. The third phase will be to analyze the data and make a recommendation on which way Baptista Farms should pull a ripper.

How Project Meets Requirements for the ASM Major

ASM Project Requirements - The ASM senior project must include a problem solving experience that incorporates the application of technology and the organizational skills of business and management, and quantitative, analytical problem solving.

Application of agricultural technology	The project will involve the application of engineering equations, tractor mechanical systems, and GPS technologies.
Application of business and/or management skills	The project will involve business/management skills in the areas of machinery management, cost and productivity analyses.
Quantitative, analytical problem solving	Problem solving will be analyzing different methods to pull a ripper, and weight transfer and wheel slip calculations.

Capstone Project Experience - The ASM senior project must incorporate knowledge and skills acquired in earlier coursework (Major, Support and/or GE courses).

Incorporates knowledge/ skills from these key courses	129 Lab Skills/Safety, 141 Agricultural Machinery Safety, 142 Machinery Management, 203 Agricultural Systems Analysis, 301 Hydraulic/Mechanical Power Systems, 321 Ag Safety, 343 Mechanical Systems Analysis, 418/419 Ag Systems Management, Technical Writing

ASM Approach - Agricultural Systems Management involves the development of solutions to technological, business or management problems associated with agricultural or related industries. A systems approach, interdisciplinary experience, and agricultural training in specialized areas are common features of this type of problem solving. (insert N/A for any area not applicable to this project)

Systems approach	The project involves the comparison of a three point mounted ripper to a pull behind to see if a pull behind ripper can still go just as deep and the tractor can pull it just as fast without having excessive weight being put on the rear axle of the tractor.
Interdisciplinary features	The project touches on aspects of mechanical systems, agricultural safety and GPS technology.
Specialized agricultural knowledge	The project applies specialized knowledge in the areas of tractor operation and GPS systems, and agricultural safety.

Project Parameters

1. The tractor must be able to pull the ripper at least 2.5 mph.
2. The percent wheel slip can not exceed 15%
3. The ripper must go at least 12" deep

List of Tasks and Time Estimate

TASK	Hours
Research	30
Visitation to ripper manufactures	10
Calculations	10
Ballast tractor	50
Data accumulation	50
Analyze data	5
Preparation of written report	40
Preparation of poster	10
TOTAL	205

Financial Responsibility

Preliminary estimate of project costs: $ N/A

Finances approved by (signature of Project Sponsor): N/A

Final Report Due: June 4, 2014 **Number of Copies**: 3

Approval Signatures		**Date**
Student:	____	__________
Proj. Supervisor:	____	__________
Department Head:	____	__________

Appendix B: Chart of down force and draft from ripper

Shank Measurements						
Vertical	Horizontal	Draft/shank	Down Force/shank	Total Draft	3pt lbs added	Drawbar Wt transfer
Inches	Inches	Pounds	Pounds	Pounds	Pounds	Pounds
3	5.4375	480	265	2400	956	357
4	7.4375	640	344	3200	1243	476
5	8.75	800	457	4000	1650	595
6	10.625	960	542	4800	1957	714
7	12.4375	1120	630	5600	2276	833
8	14.1875	1280	722	6400	2606	952
9	16	1440	810	7200	2924	1071
10	17.75	1600	901	8000	3254	1190
11	19.3125	1760	1002	8800	3619	1310
12	20.0625	1920	1148	9600	4146	1429
13	20.625	2080	1311	10400	4733	1548
14	21	2240	1493	11200	5391	1667
15	21.25	2400	1694	12000	6116	1786
16	21.25	2560	1928	12800	6959	1905
17	21.125	2720	2189	13600	7902	2024
18	20.75	2880	2498	14400	9019	2143
19	20.375	3040	2835	15200	10234	2262
20	19.8125	3200	3230	16000	11662	2381
21	19.25	3360	3665	16800	13233	2500
22	18.875	3520	4103	17600	14812	2619
23	18.375	3680	4606	18400	16629	2738
24	18.1875	3840	5067	19200	18293	2857
		Changing Variables		Units		
		Draft/in.	160	lbs/in		
		# Of shanks	5			
		Draw bar ht	18.75	In		
		Wheel base	126	In		
Distance to front two shanks			75	In		
Distance to rear three shanks			101-5/8	In		

Appendix C: Formulas used for the Chart of the Down force and draft of the ripper

Shank Measurements						
Vertical	Horizontal	Draft/shank	Down Force/shank	Total Draft	3pt lbs added	Drawbar Wt transfer
3	5.4375	=A3*$D$27	=(A3*C3)/B3	=C3*$D$28	=(75*2*D3+101.625*3*D3)/126	=(E3*$D$29)/$D$30
4	7.4375	=A4*$D$27	=(A4*C4)/B4	=C4*$D$28	=(75*2*D4+101.625*3*D4)/126	=(E4*$D$29)/$D$30
5	8.75	=A5*$D$27	=(A5*C5)/B5	=C5*$D$28	=(75*2*D5+101.625*3*D5)/126	=(E5*$D$29)/$D$30
6	10.625	=A6*$D$27	=(A6*C6)/B6	=C6*$D$28	=(75*2*D6+101.625*3*D6)/126	=(E6*$D$29)/$D$30
7	12.4375	=A7*$D$27	=(A7*C7)/B7	=C7*$D$28	=(75*2*D7+101.625*3*D7)/126	=(E7*$D$29)/$D$30
8	14.1875	=A8*$D$27	=(A8*C8)/B8	=C8*$D$28	=(75*2*D8+101.625*3*D8)/126	=(E8*$D$29)/$D$30
9	16	=A9*$D$27	=(A9*C9)/B9	=C9*$D$28	=(75*2*D9+101.625*3*D9)/126	=(E9*$D$29)/$D$30
10	17.75	=A10*$D$27	=(A10*C10)/B10	=C10*$D$28	=(75*2*D10+101.625*3*D10)/126	=(E10*$D$29)/$D$30
11	19.3125	=A11*$D$27	=(A11*C11)/B11	=C11*$D$28	=(75*2*D11+101.625*3*D11)/126	=(E11*$D$29)/$D$30
12	20.0625	=A12*$D$27	=(A12*C12)/B12	=C12*$D$28	=(75*2*D12+101.625*3*D12)/126	=(E12*$D$29)/$D$30
13	20.625	=A13*$D$27	=(A13*C13)/B13	=C13*$D$28	=(75*2*D13+101.625*3*D13)/126	=(E13*$D$29)/$D$30
14	21	=A14*$D$27	=(A14*C14)/B14	=C14*$D$28	=(75*2*D14+101.625*3*D14)/126	=(E14*$D$29)/$D$30
15	21.25	=A15*$D$27	=(A15*C15)/B15	=C15*$D$28	=(75*2*D15+101.625*3*D15)/126	=(E15*$D$29)/$D$30
16	21.25	=A16*$D$27	=(A16*C16)/B16	=C16*$D$28	=(75*2*D16+101.625*3*D16)/126	=(E16*$D$29)/$D$30
17	21.125	=A17*$D$27	=(A17*C17)/B17	=C17*$D$28	=(75*2*D17+101.625*3*D17)/126	=(E17*$D$29)/$D$30
18	20.75	=A18*$D$27	=(A18*C18)/B18	=C18*$D$28	=(75*2*D18+101.625*3*D18)/126	=(E18*$D$29)/$D$30
19	20.375	=A19*$D$27	=(A19*C19)/B19	=C19*$D$28	=(75*2*D19+101.625*3*D19)/126	=(E19*$D$29)/$D$30
20	19.8125	=A20*$D$27	=(A20*C20)/B20	=C20*$D$28	=(75*2*D20+101.625*3*D20)/126	=(E20*$D$29)/$D$30
21	19.25	=A21*$D$27	=(A21*C21)/B21	=C21*$D$28	=(75*2*D21+101.625*3*D21)/126	=(E21*$D$29)/$D$30
22	18.875	=A22*$D$27	=(A22*C22)/B22	=C22*$D$28	=(75*2*D22+101.625*3*D22)/126	=(E22*$D$29)/$D$30
23	18.375	=A23*$D$27	=(A23*C23)/B23	=C23*$D$28	=(75*2*D23+101.625*3*D23)/126	=(E23*$D$29)/$D$30
24	18.1875	=A24*$D$27	=(A24*C24)/B24	=C24*$D$28	=(75*2*D24+101.625*3*D24)/126	=(E24*$D$29)/$D$30
		Variables		units		
		Draft/in.	160	lbs/in		
		# of shanks	5			
		Draw bar ht	18.75	in		
		Wheel base	126	in		
Distance to front two shanks			75	in		
Distance to rear three shanks			101-5/8	in		

Appendix D: Depth Measurements From Both Methods

Depth Measurements Taken From the Field		
Test Spot	Drawbar Pull	3Pt Pull
	Depth	
1	21 In.	22 In.
2	21 In.	24 In.
3	23 In.	21 In.
4	22 In.	23 In.
5	20 In.	22 In.
6	22 In.	21 In.
7	22 In.	22 In.
8	21.5 In.	22.5 In.
9	22 In.	22 In.
10	22 In.	21 In.
11	21.75 In.	23.5 In.
12	21 In.	23.5 In.
13	22 In.	22.5 In.
14	20.75 In.	19 In.
15	21.5 In.	21 In.
AVG Depth	21.57 In.	22.00 In.